

Soil-geocell interfacial interaction subjected to different strain rates: macroscopic and microscopic observations

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Abstract. Reinforced soil structures exhibit enhanced stability owing to the induction of tensile strength into the soil system through the usage of reinforcements. Shear stresses developed in the soil system are transferred to the reinforcement as tensile forces via friction at the soil-reinforcement interface. This interaction remains consistent under static or monotonic loading conditions but is subjected to variation under seismic activity due to the strain rates imparted by the seismic wave propagation. In this paper, the interaction at the soil-geocell interface is studied by conducting interface shear tests under different strain rates. Surface abrasion resulting from the specimens subjected to shear under varying strain rates is assessed. The results indicate that higher strain rates do not affect the interface strength for dense specimens, thereby depicting a resilient bond being mobilized between the granular medium and the geocell strips. Further, the interface friction depicted is found to be close to the wall friction angle adopted in the conventional design of retaining walls. This study helps to gather insights on the change in interface behavior under varying strain rates which becomes more essential in the case of varying rates of slope movements.

1 Introduction

In reinforced earth structures, the stability is guided by the shear resistance at the soil-geosynthetic interface. In case of planar reinforcements like geotextiles and geogrids, the plane of interface is only along the length of the reinforcement. Hence, sliding of the reinforced material is directly governed by the interlocking strength of the interface. In a three-dimensional reinforcement like geocell-reinforced layer, multiple interfaces take part in offering shearing resistance to the structure. The vertical interface between infill soil and the geocell wall determines the effect of confinement provided by the geocell pockets; wall friction due to the interaction of the backfill with the geocell walls governs the lateral stress exerted; the horizontal interface between the geocell reinforced layers and the unreinforced zone, in combination with the tensile strength of the geocell walls governs the pullout resistance of geocell reinforced layers. In this study, the shearing resistance of soil-geocell interface is studied under varying the rate of material movement over geocell walls using interface shear tests. Further, surface abrasion caused due to such material movement is visualized by comparing both the fresh and tested geocell strips.

2 Experimental setup

Interface shear tests are conducted using large direct shear box apparatus having the dimensions 300 mm x

300 mm x 150 mm. Although the geocell walls are stiffer than the conventional geotextiles, providing sand in the lower shear box can still cause sagging of the geocell walls under normal load. The development of bowl-shaped settlement troughs with vertical displacements up to 8 mm along with lateral distortions in geotextiles have been identified when soil was filled in the lower shear box during interface shear tests [1]. Hence, to avoid any non-uniform stress distribution on the geocell walls and cause non-planar shearing at the interface, the lower shear box is packed with wooden planks. Geocell strips in the dimensions of shear box are cut from the commercial geocell pockets and they are subsequently fixed on the packing wood with the help of glue and nails. The strips are fixed in such a way that the soil-geocell interface aligns with the shear plane between the upper and lower shear boxes. It is of utmost importance to hold the geocell strips in place throughout the experiment so that the resulting data reflects only the interface shear strength without any sliding of the geocell strips over the wooden packing. In order to attain this, the geocell strips were nailed to the wooden plank. A cross-check for any post-shearing movement of the geocell strips is also made. Once the lower part of the shear box is prepared (Figure 1), the upper box is assembled upon the lower one using the inserting pins. Sand is then filled into the upper box and compacted to relative densities of 50% (RD50) and 80% (RD80). Shearing resistance is measured under the applied normal stresses of 50 kPa, 100 kPa and 150 kPa. The layout of experimental setup is shown in the Figure 2.

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The polymer density of the geocells used in this study is around 0.94 g/cc with at least 1.65 mm thickness post texturing. The strip comprises multiple rhomboidal indentations with a surface density of 22-32 per cm². Cell perforations in horizontal rows of 100 mm diameter holes cover 12% of the cell surface area. Previously conducted direct shear tests on air dried sand and the internal frictional angles (ϕ) of the same at relative densities of 50% and 80% were found to be 41.1° and 46.8°, respectively. The granular medium used is classified as poorly graded sand whose properties include $G_s = 2.64$; $C_u = 2.5$ and $C_c = 1.11$. Four different strain rates, namely 0.0315 %/s, 0.007 %/s, 0.0016 %/s and 0.0003 %/s, are applied to shear the soil-geocell interface until the occurrence of a recognizable large deformation. Necessary area correction is then applied to calculate the shear resistance mobilized at the interface.



Fig. 1. Geocell wall strips at the shearing plane

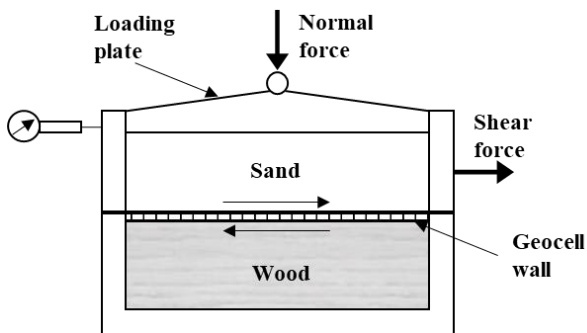


Fig. 2. Experimental layout

3 Results and Discussions

The results of the interface shear tests are assessed in terms of the interface friction angle calculated by utilizing the peak and residual shear resistance under varying normal loads. The shear behaviour of the infill soil-geocell wall (S-G) interface at a strain rate of 0.007%/s and a relative density of 80% is shown in the Figure 3 for various normal loads. The corresponding Mohr-Coulomb failure envelope utilized in interface friction angle calculations is shown in the Figure 4.

Multiple trials have been conducted for the extreme values of strain rates (0.0315 %/s and 0.0003 %/s) which is plotted with the error bars to investigate the deviation in the results from the mean values (Figures 5 and 6). Since the movement of the soil mass at 0.0003 %/s strain rate is highly negligible, the shear resistance recorded at that strain rate is considered close to static condition. It is highlighted in Figure 7 and is linked using dotted lines with the corresponding curves.

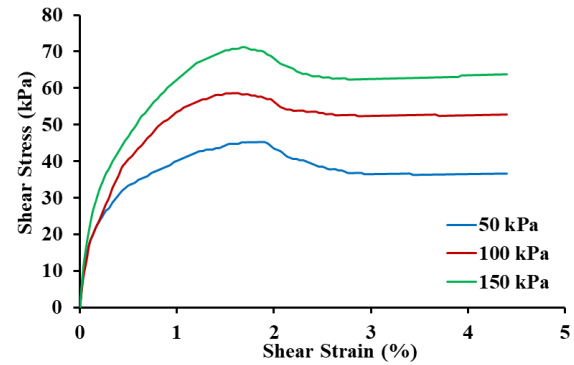


Fig. 3. Shear behaviour of infill soil-geocell wall interface at a strain rate of 0.007%/s and relative density of 80%

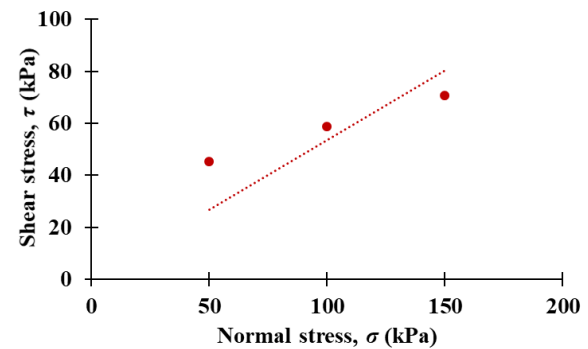


Fig. 4. Failure envelope for friction angle calculation of soil-geocell wall (S-G) interface at a strain rate of 0.007%/s

A strain rate of 0.007 %/s is taken as the reference to analyse the results as recommended by Bowles [2]. Higher strain rate indicates faster movement of sand mass over the geocell strips and lesser strain rates indicate its slower movement at the interface. The shear resistance mobilized is studied in terms of interface friction angle (δ) as shown in Figure 7. In case of loose sand, the interface friction angle is found to be maximum at 0.007%/s. An increase or decrease in strain rates exhibited reduction in the interface friction angle. Loose sand, when sheared over the interface under different strain rates, manifested significant changes in shear resistance. However, the residual shear resistance remained close to the peak resistance at all strain rates. Shear resistance attained under static condition remains nearly the same for both loose and dense specimens.

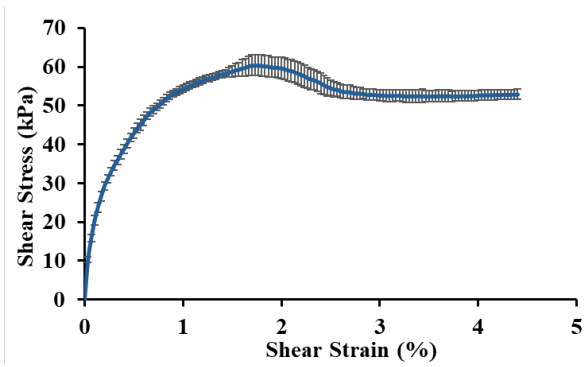


Fig. 5. Error bars plotted for S-G interface at 0.0315%/s

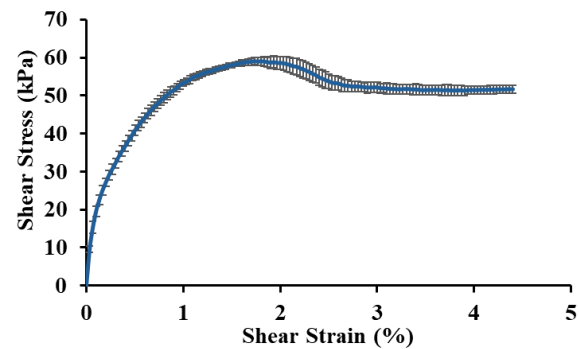


Fig. 6. Error bars plotted for S-G interface at 0.0003%/s

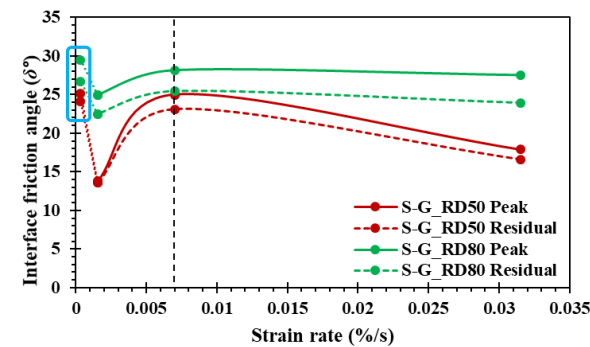


Fig. 7. Dependency of soil-geocell (S-G) interface friction angle on strain rate.

In case of dense specimens, increasing the strain rate did not noticeably affect the mobilized shear resistance, although a slight decrease in the interface friction is noted upon decreasing the strain rate. A slower movement of dense specimen over the geocell wall than 0.007 %/s leads to the dilation of sand at the interface causing the shear resistance to decrease. However, the rolling of sand particles at a faster rate in the interface caused no alteration in the shear resistance. Hence, any creep movement in the structure can diminish the interface strength for a densely compacted specimen. Further, in contrast to the loose specimens, the peak and the residual resistance are found to be distinctively different in dense specimen, thereby depicting the prevalence of strain softening at the interface.

The peak and residual friction is compared for soil-soil (S-S) [3] and soil-geocell (S-G) interfaces as shown in Figure 8. It can be noted that the behavioral trend of

peak friction is similar for both S-S and S-G interfaces for all strain rates except the S-G interface at dense state where the interface strength is found to remain unaffected by the increasing strain rate. Although the peak values differ by a significant amount, both S-S and S-G interfaces attain the residual state with almost the same frictional strength. The ratio of peak values of S-G interface friction to the S-S internal friction angle is found to be ranging from 0.37 to 0.61 and 0.6 to 0.72 for loose and dense granular medium, respectively, under varying strain rates. The average S-G interface friction for interacting dense sand follows closely the commonly adopted wall friction in geotechnical studies, i.e. $\frac{2}{3}\phi$.

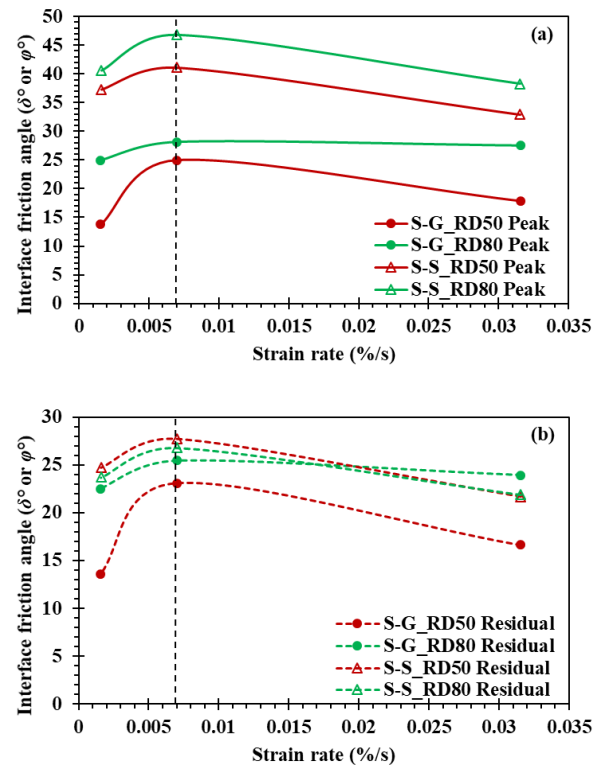


Fig. 8. (a) Peak and (b) Residual friction at S-G and S-S interfaces.

A section of the sheared geocell specimen is viewed under a Field Emission Scanning Electron Microscope (FESEM) to visualize the textural deformations caused due to shearing. For the sake of clarity, a fresh geocell specimen is used as a reference. Figure 9 shows the smooth surface before shearing and the surface abrasion on the ridges and inner surface of the rhomboidal indentations caused by the angular sand particles shearing along the surface of geocell walls. Further studies are required to delineate the influence of strain rates on the microscopic abrasion features, and thereby attempt correlating with the ascertained interface friction angles and the angularity of the granular medium.

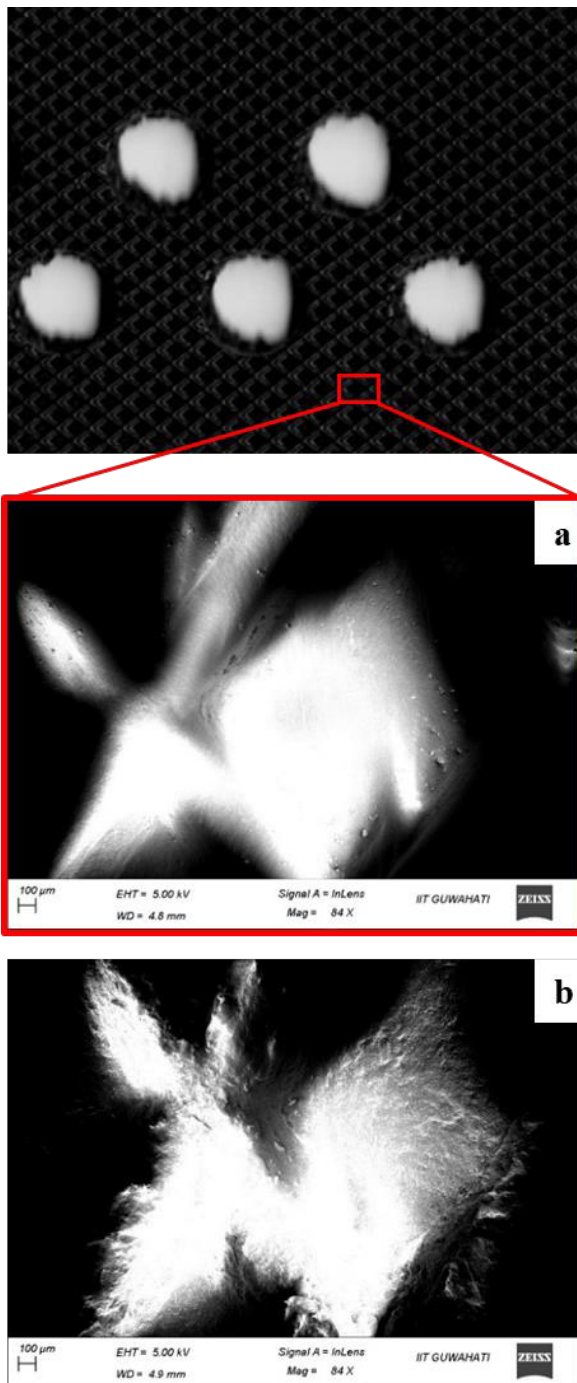


Fig. 9. SEM images showing surface abrasion on the rhomboidal indentations of geocells (a) before and (b) after shearing.

4 Conclusions

This study reflects upon the experimental investigation of soil-geocell interfacial behaviour under varying strain rates. The soil-geocell interface undergoes post-peak strain softening in case of dense specimen while the loose granular medium inhibits similar resistance at peak and residual stress states. In case of dense specimens, although increasing the strain rate did not affect the interface strength, yet a decreased strain rate representing a creep movement led to a reduction in interface friction. It may be caused due to dilation at the interface. For loose specimens, any decrease or increase in strain rate than the reference strain rate results in notable decrease in the interface strength. The average of interface friction obtained from the interaction with dense granular medium is found to closely follow the conventionally adopted wall friction, i.e. 0.67ϕ , at dense state. Increasing the strain rate decreases the peak strength of S-S interface while it remains unaffected for S-G interface owing to the surface texture of geocell material and the non-sagging shear plane. While these findings are applicable for the confined pockets of a geocell wall, the same might not apply for the frontal face of geocell pockets as they are expected to have more deformation owing to the no-confinement scenario over the outermost pockets.

References

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